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Digital transmission of multiplexed video and audio signals at 140 Mbit/s over an experimental optical-fibre transmission system

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Summary

During 1977, BBC Research Department was invited to participate in field trials of an experimental optical-fibre digital transmission system installed between the Post Office telephone exchanges at Hitchin and Stevenage. BBC equipment was specially adapted for these trials to provide multiplexed digital video and audio signals at 140 Mbit/s and to decode these signals after transmission.

High-quality audio and video signals were sent between Hitchin and Stevenage, a total distance of some 18 kilometres for the return path, over a period of one month during which time a number of tests were conducted. Brief descriptions of the equipment and tests are contained in this Report. No serious difficulties arose in the trials.

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Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

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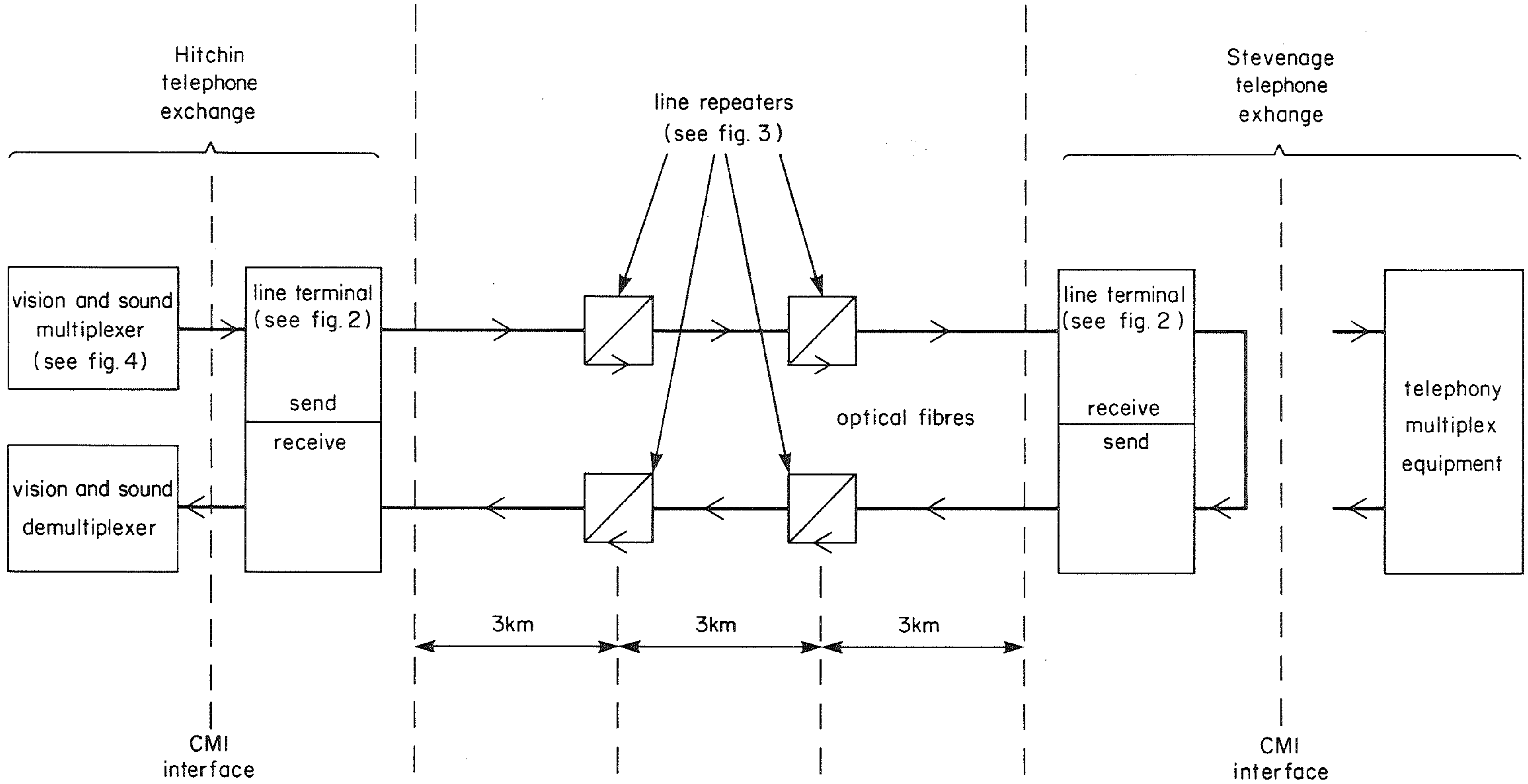

Fig. 1 - The complete system

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1. Introduction

Equipment for coding and multiplexing high-quality video and audio signals to form a 120 Mbit/s bit stream (comprising two bit-interleaved 60 Mbit/s bit streams) was developed at BBC Research Department[1] for use in field trials on a UK Post Office experimental high-speed digital line system in 1975. The results of these trials[2] showed that this system was capable of carrying the video and audio signals with imperceptible levels of impairment, but that the timing jitter and error rate of the system were influenced by the analogue video waveform. Pattern-dependent errors and timing jitter, which arise when a transmission system is carrying the highly-structured bit-stream patterns related to the television scanning format, are not readily detectable in tests using fixed patterns and pseudo-random sequences. There are, therefore, valuable tests which can be conducted on certain digital transmission systems using 'real' digital video and audio multiplexed signals.

The experimental multiplexing equipment was then used to provide a 60 Mbit/s bit-stream for further tests in conjunction with the UK Post Office in 1976.[3] On this occasion the transmission system was a 6 GHz radio link from the Post Office Satellite Earth Station at Goonhilly Downs to an Intelsat IV communications satellite in a geo-stationary orbit over the Indian Ocean. A 4 GHz radio link from the satellite back to Goonhilly completed the circuit. The performance of the digital satellite system was, under certain conditions, signal-dependent thus emphasising again the value of tests using real video and audio digitally-coded signals.

In 1977, STC (Standard Telephones and Cables Ltd.) installed an experimental 140 Mbit/s* optical-fibre system between the telephone exchanges at Hitchin and Stevenage, in collaboration with the UK Post Office. Following an invitation from STC, the opportunity was taken to carry out field trials on the optical-fibre system so building up further BBC experience on various types of digital transmission systems.

This Report gives a brief outline of the STC optical system and of the BBC coding and multiplexing equipment before describing the actual transmission tests.

2. The optical system

A simplified block schematic diagram of the complete optical-fibre transmission system[4] is shown in Fig. 1. The optical-fibre is installed in underground cable ducts between the two exchanges, which are 9 kilometres apart, with repeaters every 3 kilometres. For the tests involving multiplexed video and audio signals, it was convenient to locate the programme encoding and multiplexing equipment with the demultiplexing and decoding equipment in

* The precise bit rate is 139·264 Mbit/s corresponding to the standard fourth-order multiplex rate agreed for the European digital hierarchy.

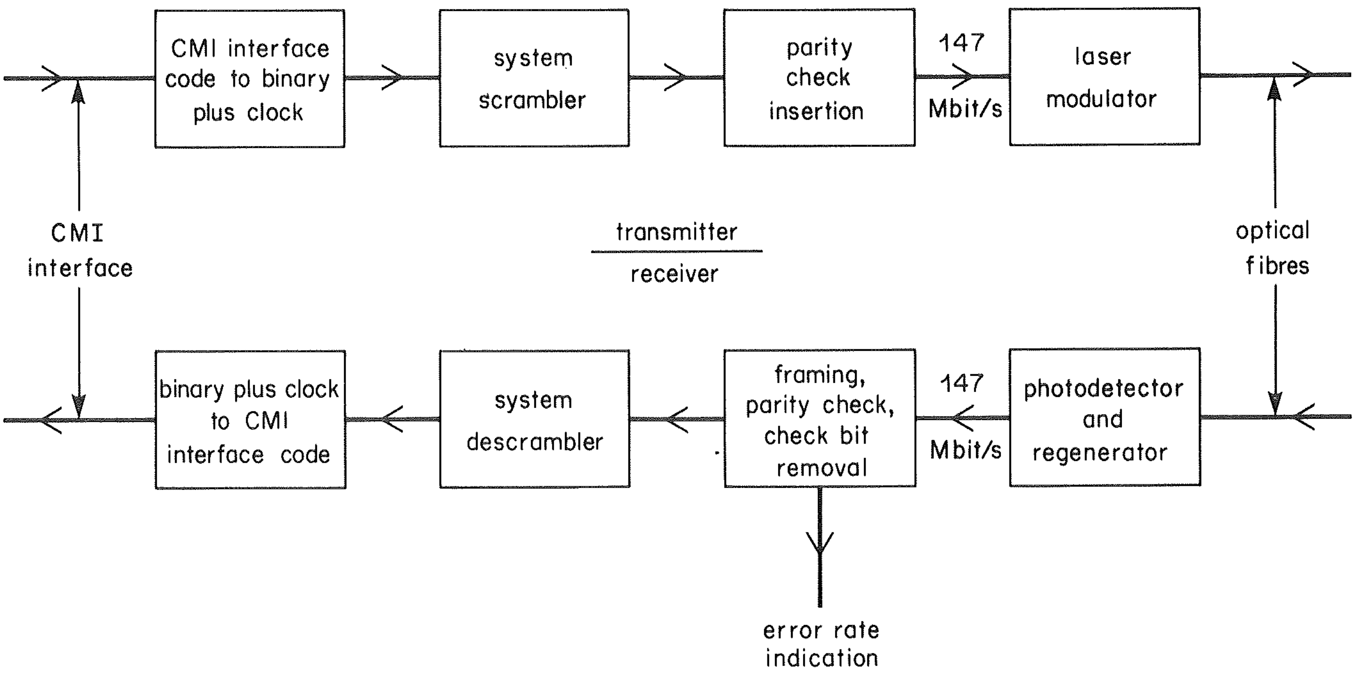


Fig. 2 - Line terminal block schematic diagram

the telephone exchange at Hitchin and to loop the 'forward' and 'return' paths of the system at Stevenage.

Interfacing with the optical-fibre system follows standard practice for the bit-rate of 140 Mbit/s and is achieved via a CMI (coded mark inversion) interface code.[5] The appropriate CMI-to-binary plus clock code converters are provided in the terminal equipment. A block schematic diagram of a line send/receive terminal is shown in Fig. 2.

The requirements that the transmitted signal should have no d.c. component, (so that a.c. coupling could be employed in the terminal equipment), that the signal should contain sufficient timing information, and that in-traffic error rate monitoring facilities would be possible led to the use of a special line code in the STC equipment. Binary signals to be transmitted over the optical system are first scrambled, and then a parity bit is inserted after every 17 data bits. The presence of the parity bit enables a check to be made on the error rate of the system, and at the same time the use of 'odd' parity ensures that at least one transition between '0' and '1' (or vice versa) occurs during each parity group of 18 bits (this means that no more than 34 consecutive '1's' or '0's' can occur in the bit stream). The bit-rate actually transmitted through the fibre is accordingly 139·264 x 18/17 = 147·5 Mbit/s. The wavelength of the gallium-arsenide striped laser light source is 0·85 micron at which the fibre attenuation is about 5 dB/km.

The repeaters which are installed in the system comprise an opto-electric detector, an equaliser amplifier with automatic gain control, a data regenerator and an electro-optical modulator. A block diagram is shown in simplified form in Fig. 3. Repeaters are used principally to remove noise and jitter from the signal by regenerating the data signal at intervals throughout the system and remodulating. By employing regeneration, the system error rate can be kept very low. Equalisers are included in the repeaters prior to the regenerators to correct for pulse dispersion introduced by the optical fibre.

Insulated copper conductors are included in the cable sheath with the optical fibres to provide engineering telephone facilities, alarm signalling and power supplies for the repeaters.[4,6] The cable used between Hitchin and Stevenage comprises four optical fibres and four insulated copper wires surrounding a central steel strength member. A polyethylene jacket provides the outer cover and the overall diameter of the cable is 7 mm.

3. The BBC experimental 140 Mbit/s coding and multiplexing equipment

The 140 Mbit/s multiplexing equipment is basically that developed for use at 120 Mbit/s for the field trials of a Post Office digital line system or at 60 Mbit/s for tests via a satellite link.[1] Modifications, involving principally an increase in the clock rate and the provision of 'dummy' extra pulses, have been made so that the equipment operates at the higher bit rate of 139·264 Mbit/s. One 'dummy' extra pulse is provided for every 6-bit video sample word, but no additional information is conveyed by these extra pulses.

Channels are provided for two high-quality System I PAL colour television signals and twelve high-quality sound signals. A block diagram of the sending equipment is shown in Fig. 4; the processes shown are reversed in the receiving equipment. For the tests on the optical-fibre system, video channel A could be provided with off-air television signals or locally-generated television test patterns, whilst channel B carried a black level, syncs and colour burst signal which was generated in digital form. Only one set of six sound-programme channels was equipped.

3.1. Video coding, scrambling and error protection

The System I PAL colour television signal to be sent in channel A of the multiplex is coded into an 8-bit parallel p.c.m. (pulse-code modulation) signal sampled at the sub-Nyquist rate of exactly twice the colour subcarrier frequency.[7] Code conversion facilities are provided so that the p.c.m. signal can be converted into 6-bit d.p.c.m. (differential pulse-code modulation) or 6-bit h.d.p.c.m.

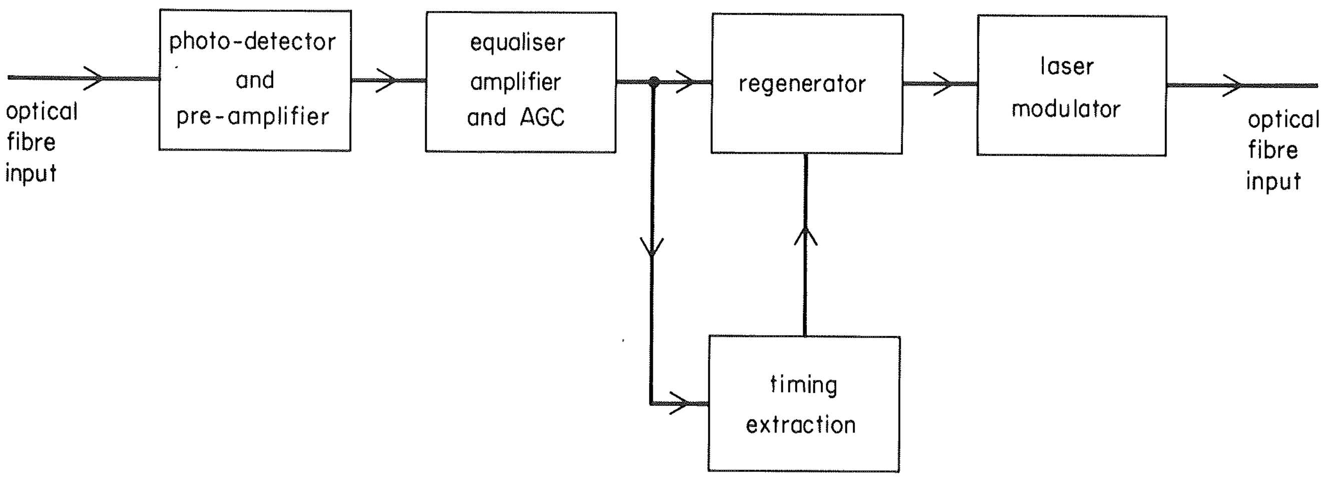


Fig. 3 - Line repeater block schematic diagram

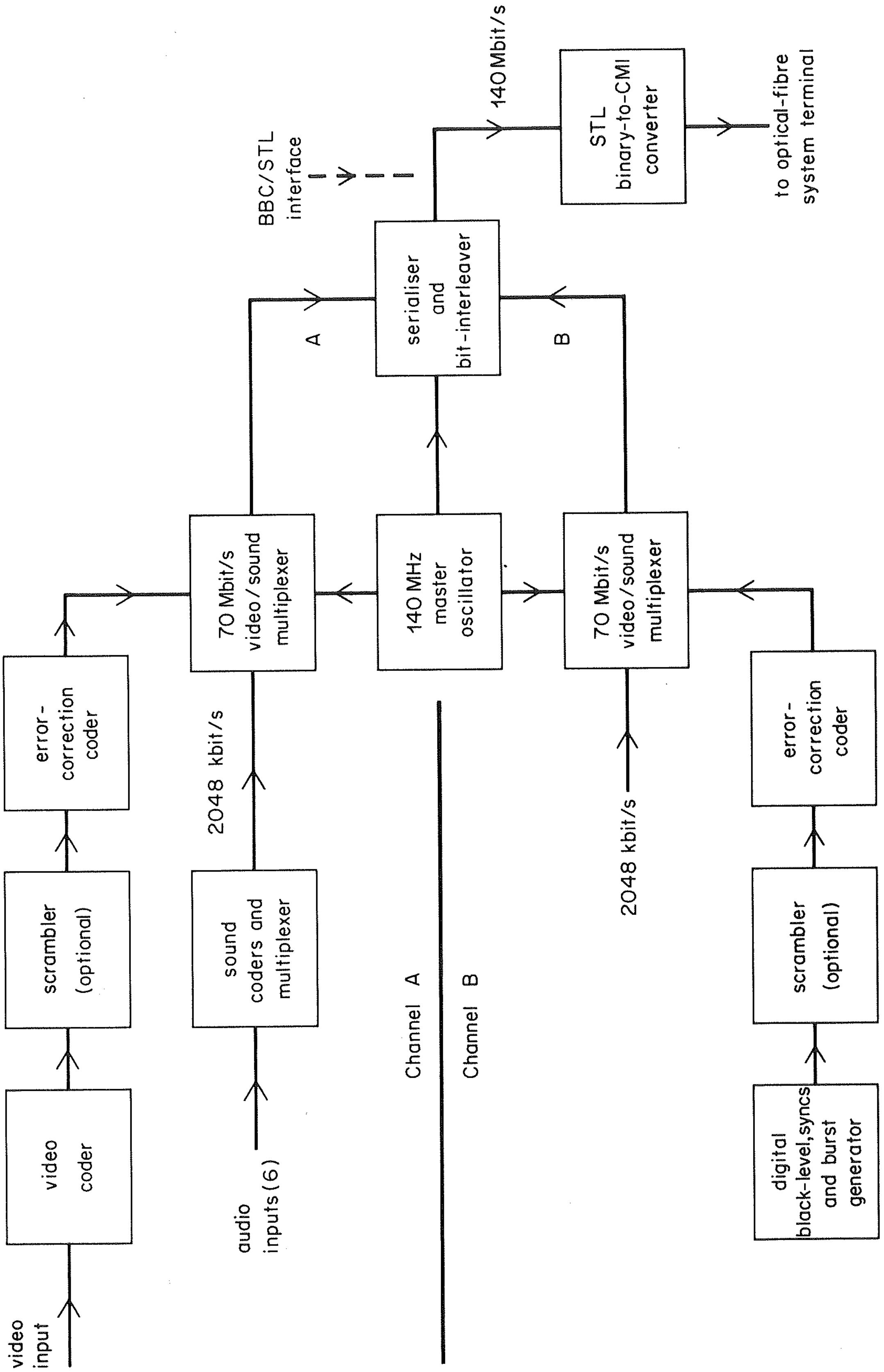


Fig. 4 - The 140 Mbit/s coding and multiplexing equipment

(hybrid differential pulse-code modulation)* giving substantially the same picture quality as the 8-bit p.c.m. signal, for transmission in the multiplex 'package'. As an alternative, the 6 most significant bits of the 8-bit p.c.m. signal can be used as a 6-bit p.c.m. signal, although this does not give such good picture quality as 6-bit d.p.c.m. or h.d.p.c.m. To minimise pattern-dependent effects, each video bit-stream is provided with an optional video scrambler to modify the patterns resulting from the television scanning format. The video scrambling facilities provided by the coding and multiplexing equipment are additional to any scrambling provided by the optical system.

Each video bit stream passes through a Wyner-Ash (16, 15) error-correction coder unit.[1,8] Six error-correction coders are employed, together with six decoders in the receiving terminal, operating independently on the six bits of the video sample word. This arrangement provides effective interlacing of the error correctors and, because of the bit interleaving of channels A and B and the presence of a dummy bit in each video channel, gives protection against bursts of up to 14 consecutive errors in the final multiplexed bit stream.

The scramblers, which are of the self-synchronising feedback type[3] precede the error-correction coders and, in the receiving equipment, the descramblers follow the error correctors. By so arranging the equipment, operation of the error correctors is not upset by the inevitable error extension produced by the descramblers.

3.2. Sound coding

The sound signals are coded using BBC 'NICAM-1'** equipment, which employs a digital companding (i.e. compressing and expanding) technique. In this equipment, six sound-programme signals are individually sampled at 32 kHz and initially quantised to 13-bit accuracy; they are then described using 10 bits per sample word.[9] An accuracy corresponding to 13, 12, 11 or 10 bits resolution is chosen for each successive block of 32 samples in each of the 6 programme channels according to the peak amplitude occurring in that block. A 2-bit scale-factor word is transmitted with each block of 32 samples to indicate to the decoder the resolution of the 10-bit samples. Finally, the 10-bit sample words from all 6 channels are multiplexed together, with the scale-factor words, parity bits for use with an error-concealment technique (protecting sample words and scale-factor words) and framing information, to form a 2048 kbit/s bit stream.

3.3. Multiplexing

A 70 Mbit/s multiplexer combines the video bit stream and the bit stream from the 2048 kbit/s sound coder and multiplexer to make a composite parallel multiplex bit stream, adds one 'dummy' extra bit for each 6-bit video sample word, and frame alignment words and increases the bit rate to 70 Mbit/s (or rather, more precisely, 69·632 Mbit/s) using positive justification.

The two synchronous 70 Mbit/s signals are fed, in parallel form, to a serialiser and bit interleaver. The resultant 140 Mbit/s serial bit stream is then converted to the CMI interface code[5] for connection to the optical system.*

3.4. Error monitoring

An error-monitoring unit in the receiving and demultiplexing equipment receives information on the number of error corrections taking place (from the video error correctors) and on the number of incorrect frame-alignment words received (from the multiplex frame detector). A digital counter in this unit can be used to count the error corrections or the incorrect frame-alignment words. It can also be set to display the bit-error rate in the received bit stream, derived either from the activity of the error correctors or from the incidence of incorrect frame-alignment words. Failure of parity framing (when the error correctors are unable to cope with the errors which are being received) or loss of multiplex frame synchronism are indicated by alarm lights and an optional audible alarm.

4. Preliminary tests

Prior to the tests on the optical-fibre system between Hitchin and Stevenage, preliminary tests were conducted at the STL** Laboratories in Harlow in order to check the operation of specially-constructed interface equipment (supplied by STL) and to identify any other problems which might arise when the BBC equipment was connected to the optical system. Of particular interest was the performance of the Wyner-Ash error-correction codecs, which form part of the BBC multiplexing and demultiplexing equipment, in a transmission system which included the optical terminal scramblers and descramblers.

Certain configurations of scrambler can, when used after the error-correction coder, affect the performance of the error correctors. Fig. 5 illustrates the error extension produced by two possible configurations of the system 15-stage scrambler/descrambler upon 16 consecutive bits in the multiplexed bit stream when a single error is present. In the first example, an error in bit 0 creates errors in the first and fifteenth following bits as the error propagates through the descrambler shift register and is introduced into the descrambled bit stream when it reaches taps 1 and 15. It will be seen from the illustration that the error corrector designated 1B receives two errors in succession, which it is unable to correct, with this configuration. In the second example, the same degree of error extension is present but the errors are distributed to separate correctors (designated 1A, 4B and 1B in the figure) which are now able to cope

* With h.d.p.c.m. coding, either p.c.m. or d.p.c.m. code-words are transmitted, the choice depending upon the dynamic characteristics of the video input signal.

** 'NICAM' stands for 'near-instantaneous companding audio multiplex'.

* The binary-to-CMI converter (and the CMI-to-binary converter for the demultiplexer equipment) were supplied by Standard Telecommunication Laboratories Ltd.

** Standard Telecommunication Laboratories Ltd. (part of STC).

EXAMPLE I

Scrambler with taps at 0, 1, 15

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	← Position of bits in shift register of descrambler.
X	X														X	← Position of extended errors resulting from a single error.
1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B			1A	1B	← Error correctors operating on bits from descrambler. (Error corrector 1A is 1st error corrector in channel A, etc. In this diagram, bits 12 and 13 are 'dummy' extra bits.)

The result of using a (0, 1, 15) scrambler is that error corrector 1B receives two errors in succession, and therefore fails.

EXAMPLE II

Scrambler with taps at 0, 7, 15

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	← Position of bits in shift register of descrambler.
X							X								X	← Position of extended errors resulting from a single error.
1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B			1A	1B	← Error correctors operating on bits from descrambler.

The results of using a (0, 7, 15) scrambler is that error correctors 1A, 4B and 1B each receive one error, which can be corrected.

Fig. 5 - The effect of two scrambler/descrambler configurations on the Wyner-Ash error correctors

with the situation. Tests in the laboratory confirmed that operation of the Wyner-Ash error correctors was upset by the presence of an optical system scrambler and descrambler with the 0, 1, 15 configuration.

It was possible to send the multiplexed video and audio signals through an optical modem without the optical system scrambler and descrambler fitted, provided that the video signals were scrambled in the BBC equipment. Under some circumstances a video signal could be sent unscrambled but this depended upon the picture content or test waveform and the type of coding (p.c.m. or d.p.c.m.). Errors in non-scrambled signals appeared to be most frequent in the region of the field sync pulses, and measurements of timing jitter revealed both line and field frequency components in the jitter waveform.

5. Main tests

The BBC coding and multiplexing equipment was installed adjacent to the optical system terminal in the telephone exchange at Hitchin. The area in the exchange set aside for the experiments is shown in the photograph of Fig. 6; the sending equipment is on the left-hand side of the picture and the receiving equipment on the right, with the optical-fibre terminal at the centre. A u.h.f. log-periodic aerial was mounted on the exchange roof to receive Band IV transmissions from the transmitter at Sandy Heath, and to provide, via an off-air receiver, 'live' video and audio signals for use in the tests. Tape-playing equipment provided two further audio signals, and video test equipment provided colour bars, colour 'chequerboard' (a pattern of coloured squares derived from vertical and horizontal colour bars), horizontal grey scale waveform, red screen and a sync, burst and black-level waveform. Another sync, burst and black-level waveform was generated digitally at the sub-Nyquist sampling rate of twice colour subcarrier frequency ($2f_{sc}$) and was available as a p.c.m. signal at the output of the generator. This p.c.m. signal was used as the digital video input for channel B throughout the tests.

The optical system was operated with a system scrambler in circuit at all times, as the use of a scrambler is an intrinsic feature of the design. For most tests, the optical system was looped at Stevenage at the terminal repeater level. This involved connecting the output of the regenerator to the laser modulator (see Fig. 2) so that the Stevenage equipment operated just as a repeater. For a short period of tests, however, the system was looped at the CMI level at Stevenage.

Fig. 6 - View of the experimental equipment installed in Hitchin telephone exchange

5.1. Error rate measurements

As already described, both the optical system and the demultiplexing equipment contained error detectors, so that the error rate could be monitored at two points simultaneously whilst the system was in traffic. The error monitor unit in the demultiplexer was normally used to indicate the number of error corrections taking place in the Wyner-Ash error corrector in channel A, although the error rate in channel B was checked with the monitor unit from time to time.

Error rates were recorded for a wide range of different conditions. The digital video signal in channel B was, for all tests, the digitally-generated sync, black level and colour burst p.c.m. signal; that in channel A was selected from the various test patterns available (colour bars, chequerboard, horizontal grey scale, red screen or sync, burst and black level) or was 'live' transmission material from the u.h.f. receiver, and coded as p.c.m., d.p.c.m. or h.d.p.c.m. Two different configurations of system scrambler were used in the optical terminal (corresponding to the examples shown in Fig. 5), and the video scramblers* in the BBC equipment were used to give different combinations of scrambled and non-scrambled digital video signals.

The error rate of the optical system was checked from time to time during each day with the 100% chequerboard signal in the video A channel. A variation in the system error rate from 4·5 in 10^9 to 1·6 in 10^8 (a range of about 3·5 : 1) was observed, and this appeared to be related to the level of activity of the telephone switchgear in the exchange. This aspect was not investigated further, however.

Detailed results of the error-rate measurements are given in Table I and Table II.

5.2. Measurements of timing jitter

Clock signals recovered in digital repeaters and receiving terminal equipment inevitably contain some residual timing disturbances (known as 'jitter'), which will be imparted to the digital signals whenever they are retimed. Jitter can impair system performance by increasing the incidence of errors and by phase modulation of analogue signal samples in digital-to-analogue converters.

Purpose-built measuring equipment was used to monitor timing jitter on the received signal at the CMI interface between the optical terminal and the video and audio demultiplexing equipment. Jitter was recorded with the same conditions as for the error tests, but a different combination of video signals was selected for transmission in channel A, to include signals which had been found to give the highest levels of jitter. The results obtained are shown in Table III. Tests were also conducted with a pseudorandom sequence of digits in place of the A channel video signal, and these results are included in the table.

* The video scramblers were of the self-synchronising feedback type (as mentioned in Section 3.1) with 6 stages and tapped to give the (0, 1, 6) configuration.

5.3. Tests on system looped at CMI interface level in Stevenage exchange

A brief series of tests was conducted with the connection between the 'outward' and 'return' paths at Stevenage made at the CMI interface level instead of the terminal repeater level. This is best illustrated by referring to the block schematic diagram of Fig. 2. When the system operates with a loop at the terminal repeater level, the output of the regenerator is connected directly to the input of the laser modulator (i.e. only the two blocks on the right-hand side of the diagram are involved in the loop connection). Looping at CMI interface level involves the entire line terminal equipment shown in the diagram; in other words, the connection between outward and return paths is made at the extreme left-hand side of the diagram.

When the system was looped at the CMI interface level, parity information from the incoming signal at Stevenage (the 'outward' path from Hitchin) was removed by the parity checking circuits, so that the system error-monitoring circuits at Hitchin detected only the errors introduced on the 'return' path from Stevenage. This did not affect the operation of the Wyner-Ash error correctors or the error monitoring circuits in the BBC demultiplexing equipment. The error rates observed in the video signal, when the system was looped at the CMI interface level, were very similar to those recorded when the system was looped at the terminal repeater level, but the error rate indicated by the error detector in the optical system terminal equipment was reduced by a factor of 10 in this condition. This was a greater reduction than had been anticipated (one would have expected the error rate indication to he halved), and it was deduced therefore that the outward path, from Hitchin to Stevenage, was contributing substantially more errors than the return path.

Measurements of timing jitter gave results which were rather higher when the system was looped at the CMI interface level. It is possible that this increase in jitter could have been caused by the introduction of an additional phase-locked loop into the system at Stevenage, but this was not investigated.

5.4. Subjective tests

Throughout the tests, informal subjective assessments of received picture and sound quality were made. Consistently good picture and sound quality was obtainable from the system during the entire period of the tests.

6. Discussion of results

The optical-fibre system was able to carry multiplexed digital audio and video signals between Hitchin and Stevenage with negligible impairment to picture or sound quality during the course of the tests.

The bit-error rate which was present in the optical system when it was carrying the telephony multiplex traffic was about 2 in 10^{10}. This rose to an average value of about 8 in 10^9 when digital video signals were being sent

TABLE I

Results of error measurements with optical system scramber I (0, 1, 15 configuration) in circuit

	Video Signal	A CHANNEL Coding (P = p.c.m. D = d.p.c.m. H = h.d.p.c.m.)	A CHANNEL Video Scrambler (S = scrambled N = not scrambled)	B* CHANNEL Video Scrambler (S = scrambled N = not scrambled)	BIT-ERROR RATES In optical system	BIT-ERROR RATES Measured by video error corrector in Channel A	REMARKS
							Measurements made at Hitchin Telephone Exchange on 9th November, 1977
1	100% Chequerboard	H	N	N		1 in 10^3	High error rate in demultiplexed video bit stream, caused by instrumental defect. Optical system error rate much lower (not recorded**).
2	100% Chequerboard	H	All combinations tested. Bit-error rate appeared to be unaffected by scrambling the video bit stream(s).		~4·5 in 10^{10}	~2 in 10^8	Measurements at Hitchin on 10th November 1977
3	Sync, burst & black level	H			~4·5 in 10^{10}	~2 in 10^8	At this time, base error rate of system was variable. Figures are approximate mean values.
4	100% Chequerboard	D			~4·5 in 10^{10}	~2 in 10^8	Extended errors from system scrambler I caused failure of video error corrector (see Section 4), so video error rate in adjacent column is incorrect. True video error rate was probably much higher.
5	Sync, burst & black level	D			~4·5 in 10^{10}	~2 in 10^8	

* B channel video signal was sync, burst & black level with p.c.m. coding, for all tests.

** Alarm indication signal (AIS) was appearing in the video bit-stream. Subsequent tests were conducted with the AIS disabled at the optical system descrambler.

TABLE II

Results of error measurements with optical scrambler II (0, 7, 15 configuration) in circuit

	A CHANNEL			B* CHANNEL	BIT-ERROR RATES		REMARKS
	Video Signal	Coding (P = p.c.m. D = d.p.c.m. H = h.d.p.c.m.)	Video Scrambler (S = scrambled N = not scrambled)	Video Scrambler (S = scrambled N = not scrambled)	In optical system	Measured by video error corrector in Channel A	Measurements made at Hitchin Telephone Exchange on 9th November 1977
1	100% Chequerboard	H	N N S S	N S N S	4·5 in 10^9 5·4 in 10^9 4·7 in 10^9	1·8 in 10^8 2·3 in 10^8	First measurement of tests. Bit-error rates (for all measurements) were determined by counting errors in a 30-second period.
2	Sync, burst & black level	H	N N S S	N S N S	6·6 in 10^9 7·7 in 10^9 1·1 in 10^8 1·2 in 10^8	1·8 in 10^8 2·3 in 10^8 4·1 in 10^8	
3	100% Chequerboard	D	N N S S	N S N S	1·4 in 10^8 2·0 in 10^8 1·5 in 10^8	5·3 in 10^8 5·9 in 10^8	
4	100% Chequerboard	H	N	N	1·6 in 10^8	5·9 in 10^8	Repeat of first measurement, made approximately 1 hour later. Error rate had increased in this time.
5	Sync, burst & black level	D	N N S S	N S N S	1·0 in 10^8 9·5 in 10^9 1·3 in 10^8 8·1 in 10^9	4·1 in 10^8 2·9 in 10^8 5·9 in 10^8 2·9 in 10^8	
6	100% Chequerboard	P	N N S S	N S N S	1·1 in 10^8 7·7 in 10^9 1·3 in 10^8 8·4 in 10^9	4·7 in 10^8 4·1 in 10^8 5·3 in 10^8 3·5 in 10^8	
7	Sync, burst & black level	P	N N S S	N S N S	8·6 in 10^9 4·5 in 10^9 1·2 in 10^8 8·6 in 10^8	2·9 in 10^8 1·8 in 10^8 4·7 in 10^8 3·5 in 10^8	
8	100% Chequerboard	H	N	N	9·0 in 10^9	3·5 in 10^8	Repeat of first measurement after approximately 2 hours. Error rate had fallen, but was still higher than initial level.
9	100% Chequerboard	P		All Combinations Tested		~2·3 in 10^8	Measurements at Hitchin on 10th November 1977
10	Sync, burst & black level	P				~2·3 in 10^8	All error rate measurements were very close during these tests, and individual results were not recorded.
11	Horizontal grey scale	P				~2·3 in 10^8	

* B channel video signal was sync, burst & black level with p.c.m. coding for all tests.

TABLE III

Results of timing jitter measurements

	A CHANNEL			B CHANNEL	TIMING JITTER IN RECEIVED 140 MBIT/S BIT STREAM (DEGREES)		REMARKS	
	Video Signal	Coding (P = p.c.m. D = d.p.c.m. H = h.d.p.c.m.)	Video scrambler (S = scrambled N = not scrambled)	Video scrambler (S = scrambled N = not scrambled)	R.M.S.	Peak-to-peak	Tests conducted on 15th November 1977	
1	Full field red screen	D	N N S S	N S N S	8·97 8·97 7·13 7·25	86·05 102·04 73·76 73·76	Television line-rate structure visible in jitter waveform. More random structure.	Scrambler II in optical system
2	Full field red screen	P	N N S S	N S N S	8·61 9·22 7·13 7·25	86·06 99·58 73·76 70·08	As above	
3	Horizontal colour bars	P	N N S S	N S N S	10·20 10·45 6·76 7·25	86·06 98·35 71·31 68·85	Strong luminance component with 10 ms period observed in jitter waveform.	
4	Horizontal colour bars	D	All combinations		Similar results to previous row		Luminance component removed when going from p.c.m. to d.p.c.m.	
5	Live transmission	D	N	N	7·38 to 9·84	88·52	R.M.S. value slowly varying.	
			S	S	7·25	73·76	Very stable r.m.s. reading	
6	Live transmission	D	N	N	7·38 to 9·84	86·06	R.M.S. value slowly varying. Scrambler I in optical system.	
7	Pseudo-random binary sequences at 139·264 Mbit/s		$2^{17}-1$ $2^{7}-1$		6·90 6·30	78·68 71·30	Scrambler II in optical system	
8			$2^{17}-1$ $2^{7}-1$		6·76 6·15	88·5 63·9	Scrambler I in optical system	

over the system. The bit-error rate in the bit stream fed to the BBC demultiplexing equipment was rather higher than this, owing to the error extension produced in the optical system descrambler. On average, the bit-error rate was registered by the video error-monitoring facility in the demultiplexing equipment was about 3 in 10^8 (i.e. about four times the error rate in the optical system). The errors appeared to be randomly distributed and well within the correction capability of the Wyner-Ash error correctors in the BBC demultiplexing equipment. The error performance of the optical system, although acceptable, differed from that found from tests on electrical cable systems. The previous tests on 120 Mbit/s cable systems[2] showed that the cable-system error rate was normally virtually zero and this was for a considerably longer circuit (200 km with 106 regenerative repeaters) than the optical system (18 km with 4 repeaters). The precise cause of the errors in the experimental optical system was not clear but it might possibly have been non-optimal functioning of the timing-extraction circuits in some repeaters particularly in the circuit from Hitchin to Stevenage.

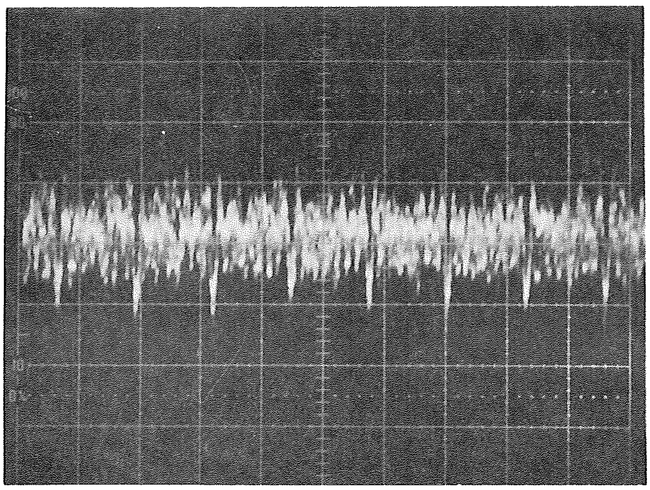
The measurements of timing jitter revealed that, when video and audio signals were being sent over the system, the lowest levels of peak-to-peak jitter were obtained when both digital video signals were scrambled. No significant difference in jitter performance could be detected when the optical system scrambler was changed from scrambler II to scrambler I. In the tests with live television transmissions providing the video signal for channel A, and no video scramblers in use, a slow variation could be observed in the r.m.s. jitter. This was found to be a result of the slight difference between the field frequency of the television transmission and that of the test equipment which was providing the video signal for channel B. When the video scramblers were used, the variation disappeared. No conditions were found where the jitter amplitude was sufficiently high to cause bit errors.

Inspection of the jitter waveform in the jitter-measuring equipment revealed that without video scrambling, components at the television line rate of 15·625 kHz were present, but were removed when scrambling was introduced. The jitter waveforms are shown in the photographs of Fig. 7 and the corresponding spectra are shown in Fig. 8 (picture content was found to have very little effect).

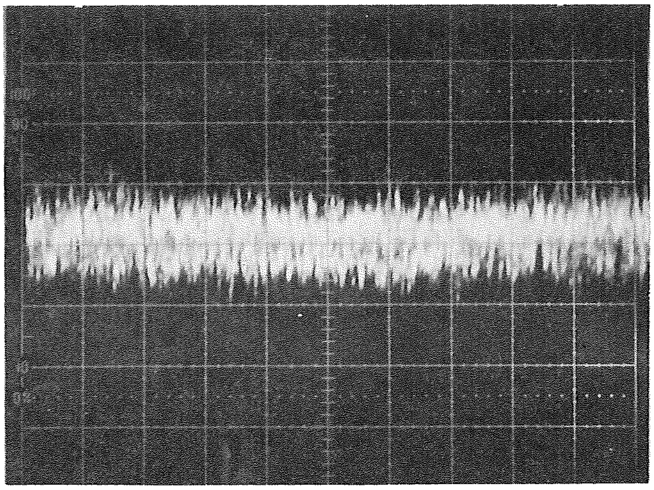
7. Conclusions

Tests conducted on an experimental 140 Mbit/s optical-fibre transmission system have shown that no serious difficulties arose when transmitting digital sound and television signals. Although some pattern dependency was detected, the consequential effects on timing jitter and error performance were well within acceptable limits and no impairment of the audio or video signals could be perceived by listeners and viewers during informal subjective tests. The difference in bit-error rate between the Hitchin-Stevenage and Stevenage-Hitchin sections of the system seems to imply that some of the repeater timing-extraction circuits were not functioning optimally during these tests, and may have been contributing to the slight pattern dependency which was observed.

The results obtained indicate that the optical transmission system is substantially transparent, owing to the incorporation of the self-synchronising system scrambler. Nevertheless they also show that additional scramblers may be beneficial when highly-structured signals, such as digital television signals, form part of the traffic. Furthermore, the tests have emphasised that care must be taken to ensure that scramblers which operate on signals protected by error-correction codes do not interfere with the functioning of the error corrector.



(*a*)

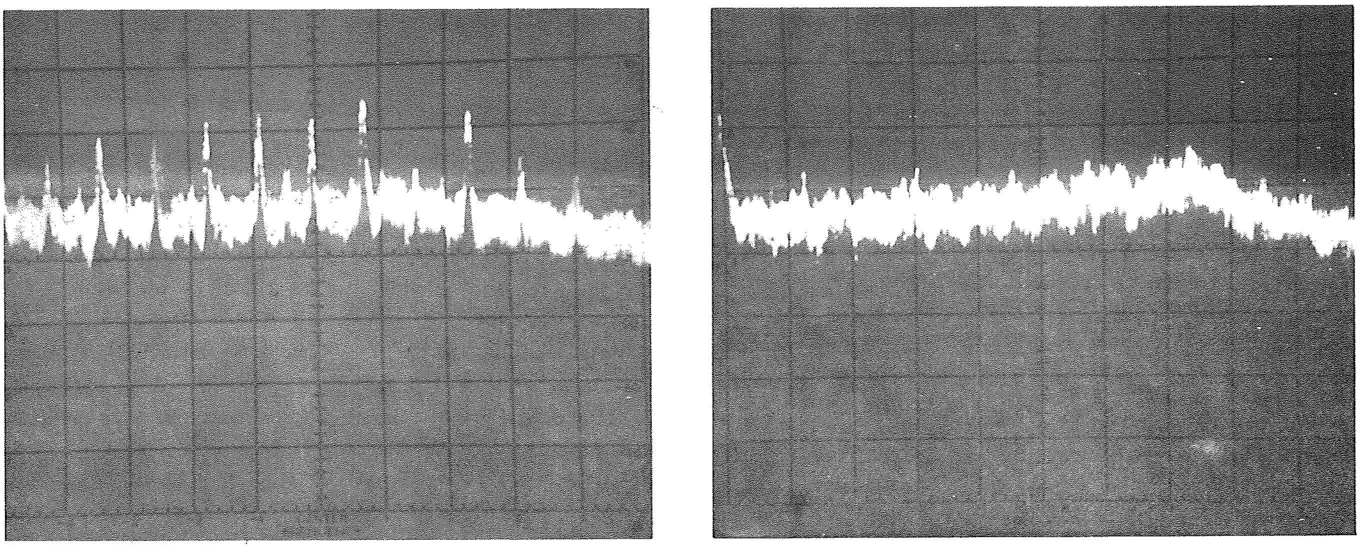


(*b*)

Fig. 7 - Jitter waveforms from STL jitter-measuring equipment connected to the output of the optical system

Vertical scale: 25° per major division   Horizontal scale: 50 μs per major division

(*a*) Without video scrambling   (*b*) With both video signals scrambled



(*a*) (*b*)

Fig. 8 - Spectrum of jitter signal from STL jitter-measuring equipment connected to the output of the optical system
Vertical scale: 10 dB per major division Horizontal scale: 20 kHz per major division
(*a*) Without video scrambling (*b*) With both video signals scrambled

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